

“Green” Composites from Cellulose Fabrics and Soy Protein Resin

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Fiber-reinforced composites have been used for many applications from aerospace to automotive parts and from sporting goods to circuit boards. Most commercially produced fiber-reinforced composites use petroleum based or synthetic fibers and resins that are non-degradable. Our goals are to develop fully-degradable, environment-friendly (“green”) composites using cellulose fibers, yarns and/or fabrics as reinforcement and modified soy protein polymer as the resin. We also seek a fundamental understanding of the interaction of fiber and soy protein.

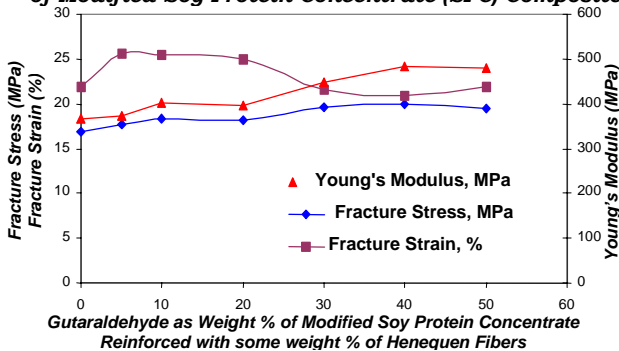
Random short fiber “green” composites have moderate mechanical properties and can be used in non-structural applications. The unidirectional continuous fiber composites have tensile properties close to steel, but on a per weight basis (typical steel/composite density ratio ~6), these “green” composites are significantly superior to steel and could be used for indoor structural applications in housing and transportation. After their use, these composites can be easily disposed of or composted without harming the environment.

Soy protein is commercially available in three grades: soy flour (SF) containing about 50% protein, soy protein concentrate (SPC) containing 70% protein and soy protein isolate (SPI) containing 90% protein. We have modified both SPC and SPI by various means to improve their mechanical properties prior to using as resin to make composites. Because of the highly polar groups on both cellulose and SPC the fiber/resin interface is expected to be strong.

Adding glutaraldehyde (GA) as a cross-linking agent to soy protein concentrate gave a modified SPC (M-SPC) which had improved modulus and strength and increased thermal resistance (see Graphs below). Also, addition of poly(vinyl alcohol) (PVA) improved properties, especially toughness, by providing added entanglements.

An SPI modified with stearic acid had a more than 2.5 times higher modulus, improved thermal stability and decreased moisture absorption (below 13% vs. over 16%). Less moisture absorption usually means improved mechanical properties of the resin as well as of the composite. In addition the composites swell less because they absorb less moisture; such dimension changes in some applications could be critical.

Effect of Glutaraldehyde % on the Mechanical Properties of Modified Soy Protein Concentrate (SPC) Composite Reinforced with some weight % of Henequen Fibers



Using modified soy protein as the resin, we developed flax yarn-reinforced unidirectional, biodegradable composites and flax fabric-reinforced panels having sufficient mechanical properties.

Flax Yarn- and Fabric-Reinforced Composites

We fabricated unidirectional flax yarn-reinforced composites using M-SPC resin. To fabricate yarn composites, yarns were aligned under slight tension and dipped into procured resin. When yarns were kept under high stress, composites prepared had dramatically increased tensile and flexural properties (see Table). These composites have sufficient mechanical properties (when compared to other materials, such as wood and soft steel) to find use in some interior structural applications.

Mechanical Properties of Flax Yarn / M-SPC Composites

| Composite Preparation | Test Type | Tensile or Flex stress (MPa) | Tensile or Flex strain (%) | Young's or Flex modulus (GPa) |
|---|-------------------------|------------------------------|----------------------------|-------------------------------|
| Composites with Yarns under slight stress (45%) | Tensile (Longitudinal) | 126.1 (13.6)* | 11.6 (7.6) | 2.24 (8.8) |
| | Flexural (Longitudinal) | 86.1 (13.2) | 15.1 (17.5) | 1.18 (23.8) |
| Composites with Yarns under high stress (60%) | Tensile (Longitudinal) | 259.5 (10.8) | 10.7 (5.6) | 3.71 (23.7) |
| | Flexural (Longitudinal) | 174.5 (27.5) | 2.6 (15.4) | 10.44 (27.4) |

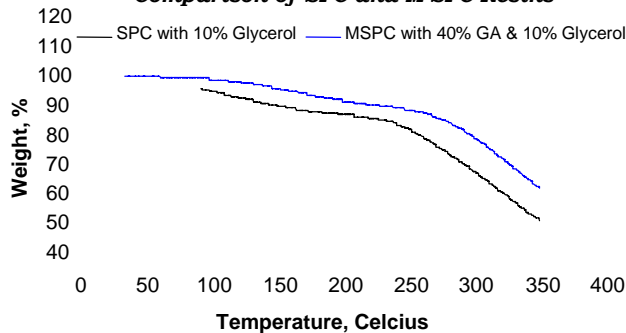
Numbers in parentheses show the percent coefficient of variation for each type of measurement.

We also prepared fabric-reinforced composites using SPC, modified with both GA and PVA, and four layers of fabrics coated with procured resin. With tensile stress values in the range of 50-55 MPa, these composites could be used as panels in many applications. The fracture sequence of the fabric reinforced composite shows that the fracture is not catastrophic and indicates high toughness (see Photo at top of next page).

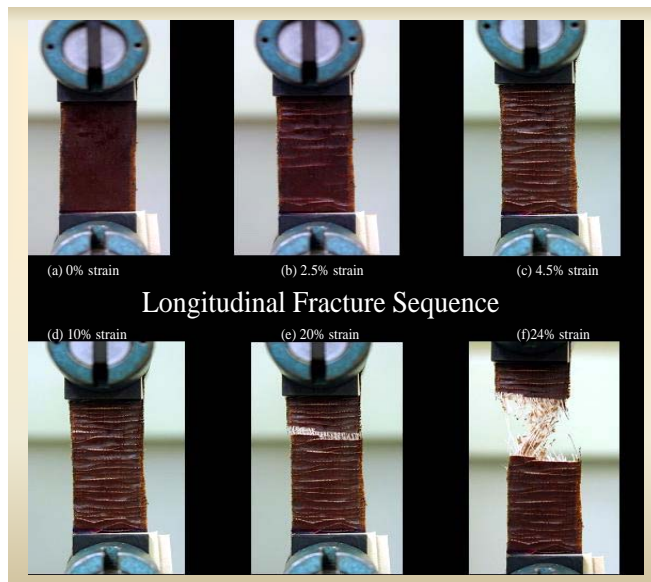
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Industry Interactions: 2 [Archer Daniels Midland, DuPont] **Other Interactions:** Academic:2; Government: 1.

Thermogravimetric Analyzer (TGA) Thermograms Comparison of SPC and M-SPC Resins



Fabric Reinforced Composite Fracture Sequence



Project Web Address:

<http://www.human.cornell.edu/units/txa/research/ntc/F01-CR01-A3.pdf>

For Further Information:

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2. S. Chabba, G. T. Matthews and A. N. Netravali, *'Green' Composites Using Modified Soy Flour and Flax Yarns*; submitted to Advanced Composites Letters (2003).
3. S. Chabba and A. N. Netravali, *'Green' Composites Part 1: Characterization of Flax Fabric and Glutaraldehyde Modified Soy Protein Concentrate Composites* submitted to J. Mater. Sci. (2003).
4. S. Chabba and A. N. Netravali, *'Green' Composites Part 2: Characterization of Flax Yarn and Glutaraldehyde/Poly(vinyl alcohol) Modified Soy Protein Concentrate Composites*; submitted to J. Mater. Sci., (2003).
5. P. Lodha and A. N. Netravali, *Thermal and Mechanical Properties of Green Plastics Molded from Stearic Acid Modified Soy Protein Isolate*, Industrial Crops and Products, in press, (2004).
6. A. N. Netravali, *Biodegradable 'Green' Composites Using Ramie Fibers and Soy Protein Polymer*, Chapter 18 in Natural Fibers, Plastics and Composites, Eds. F. T. Wallenberger, and N. E. Weston, Kluwer Academic Publishers, Boston 321 (2004).
7. P. Lodha and A. N. Netravali, *Characterization of Interfacial and Mechanical Properties of "Green" Composites with Soy Protein Isolate and Ramie Fibers*, J. Mater. Sci. **37**:3657 (2002).
8. Sunghyun Nam and A. N. Netravali, *Characterization of Ramie Fiber/Soy Protein Concentrate (SPC) Resin Interface* submitted to J. Adhesion Sci. Technol. (2002).
9. P. Lodha and A. N. Netravali, *Thermal and Mechanical Properties of Green Plastics Molded from Stearic Acid Modified Soy Protein Isolate*, submitted to Industrial Crops and Products (2003).
10. A. N. Netravali and S. Chabba, *Composites Get Greener'*, invited review article, Materials Today, 22 (April 2003).
11. S. Chabba and A. N. Netravali, *Characterization of 'Green' Composites using Henequen Fibers and Modified Soy Protein*, Proceedings, International Workshop on "Green" Composites, Tokushima, Japan (Nov 2002), p.1.
12. H. Takagi, C. W. Winoto and A. N. Netravali, *Tensile Properties of Starch-based 'Green' Composites Reinforced with Randomly Oriented Discontinuous Mao Fibers*, Proceedings, In-

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Anil N. Netravali, a Professor of Fiber Science at Cornell, joined the staff in 1984 as a postdoctoral associate in Materials Science and Engineering and then in 1987 joined faculty in the Dept. of Textiles and Apparel. Anil earned B.S. his M.S. in textiles in 1973 from Bombay Univ. and an M.S. (1980) and Ph.D. (1984) in fiber and polymer science from NC State. His research interests include high strength fibers, advanced "Green" composites, fiber/resin interface modification, polymer durability and geotextiles.



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